An Astronaut BioSuit™ System for Exploration Missions

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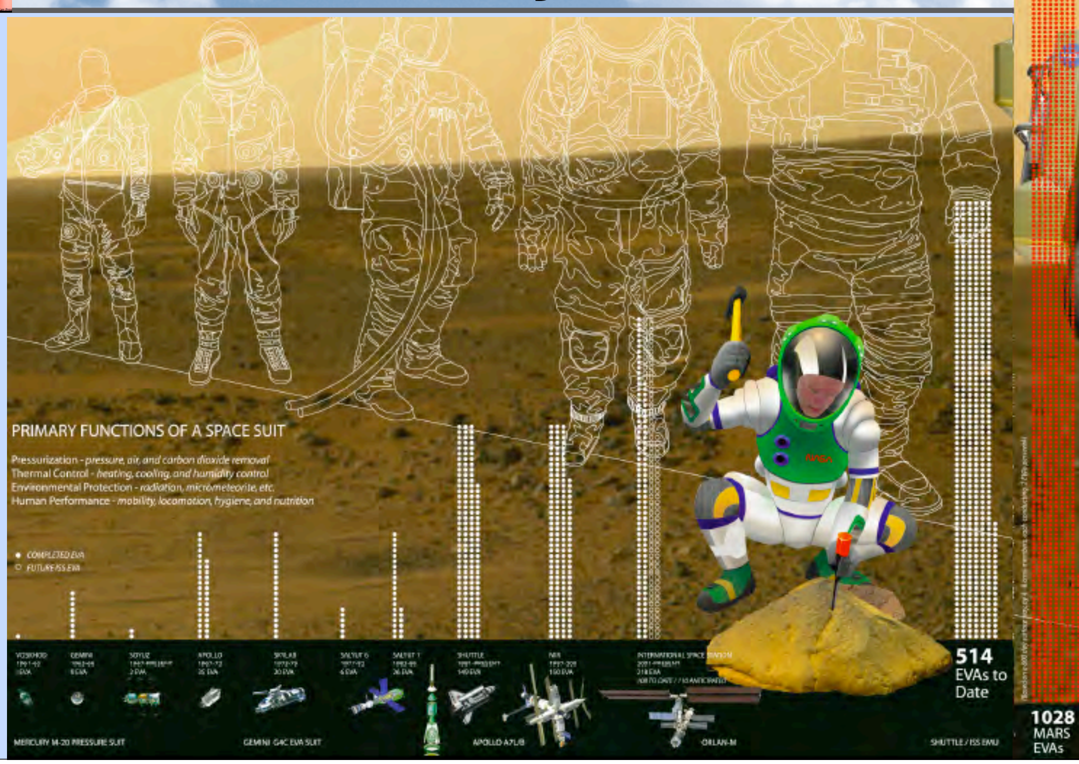
NIAC NASA Institute for Advanced Concepts

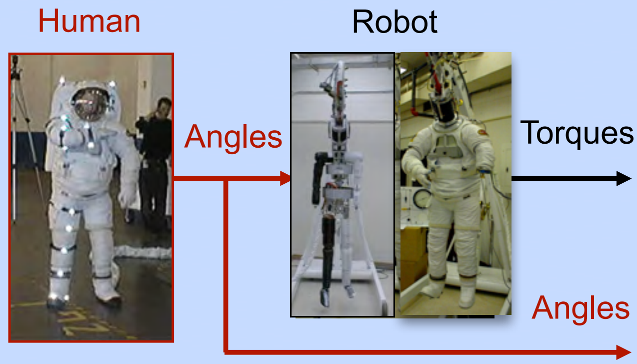
NIAC Fellows Meeting
ANSER Arlington, VA
17 November 2011

History of EVA



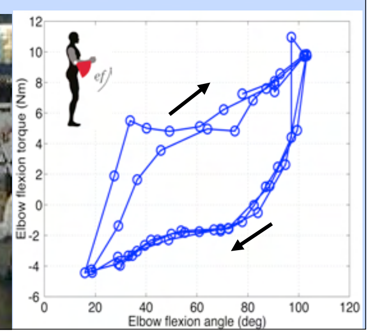
Current State-of-the-Art

- **NASA EMU spacesuit**
  - World's smallest spacecraft
  - Pressure: 27 kPa (4.3 psi)
  - Air, Thermal, Humidity
  - Heavy: 140 kg (~300 lb)
  - NOT a locomotion suit

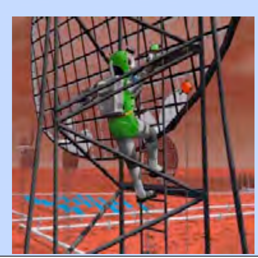


M. Tallchief

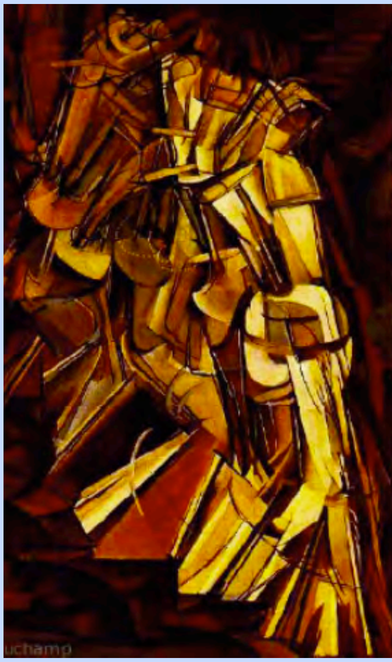
Robotic Space Suit Tester (RSST)



Creativity, Imagination, Innovation in Spacesuit Design



The Art of Engineering and Design



The Art of Engineering and Design

Duchamp's Nude Descending a Staircase, No 2.

EVA Research: Nighttime Exploration in Arizona

NIAC-funded Bio-Suit™ System for Exploration Class Missions

NIAC Science Council Member Between 2001-2003

Phase I

2001 NASA Goddard Space Flight Center/USRA
PI: Astronaut Bio-Suit System for Exploration Class Missions

Phase II

2003–04 PI: Astronaut Bio-Suit System for Exploration Class Missions – Phase II

2004–05 PI: Astronaut Bio-Suit System for Exploration Class Missions – Phase II

Phase III (?)

2005–06 NASA Goddard Space Flight Center

2005–06 NASA Headquarters

Research Partners & Advisors

Trotti & Associates, Inc. (TAI)

TAI is a design consulting firm helping private and public organizations visualize and develop solutions for new products, and technologies in the areas of Architecture, Industrial Design, and Aerospace Systems.

Award-winning designs for: Space Station, South Pole Station, Underwater Habitats, Ecotourism. (Phase I and II)

Midé Technology Corporation is a R&D company that develops, produces, and markets High Performance Piezo Actuators, Software, and Smart (Active) Materials Systems; primarily for the aerospace, automotive and manufacturing industries.

Advisory Board

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Dr. Cady Coleman, NASA astronaut.
Dr. Buzz Aldrin, Apollo 11 astronaut.

Dr. Michael Gernhardt, Dr. Claude Nicollier, Dr. Daniel Burbank,
Dr. Joseph Tanner, Dr. Bruce Webbon, Dr. Bernie Luna, and Dr. Paul Webb.

Background and Contributions

Space Suit Mobility

Iberall, 1964

Empty Suits
Dionne, 1991
Abramov, 1994
Menendez, 1994

Human Subjects
Morgan et al., 1996
Newman et al., 2000
Schmidt et al., 2001
Carr, 2005

Performance & Modeling

Biomechanics & Energetics
Streimer et al, 1964; Wortz & Prescott, 1966; Wortz, 1968; Robertson & Wortz, 1968; Johnston, 1975
Newman et al., 1993, 1994, 1996
Carr and Newman, 2005, 2006

Modeling
Iberall, 1970
Rahn, 1997; Schmidt, 2000-2001; Carr, 2001, Bethke et al., 2004; Bethke, 2005

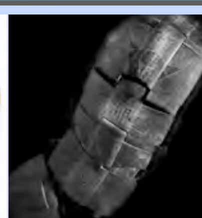
Enhanced Performance
Blaya, Newman, Herr, 2003

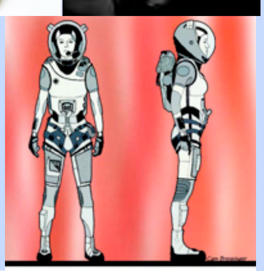
Bio-Suit Concepts/ Systems Engineering

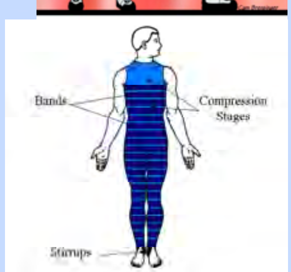
Mechanical Counter Pressure-Related
Webb, 1968
Annis and Webb, 1971
Clapp, 1983
Tourbier *et al.*, 2001
Korona, 2002
Waldie *et al.*, 2002
Tanaka *et al.*, 2003
Pitts, Newman et al., 2001
Newman et al., 2004
Sim et al., 2005

Engineering Systems
Saleh, Hastings, Newman, 2002, 2003, 2003,2004, 2005
Jordan, Saleh, Newman, 2005, 2006

Revolutionary Design – *Bio-Suit™ System*







BioSuit™ Design:

- Mechanical Counter Pressure (MCP) Bio-Suit
- Extremely mobile gloves and boots
- Biodesign: Armadillo-like articulated back structure
- Modular life support backpack

Systems Engineering: req's., design life, model, interchangeable components

Idea: Custom-fit *skin suit* to an individual human/digital model

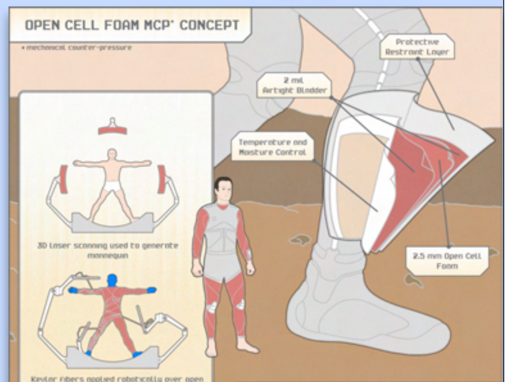
Space & Earth Applications: Mobility, Performance and Safety

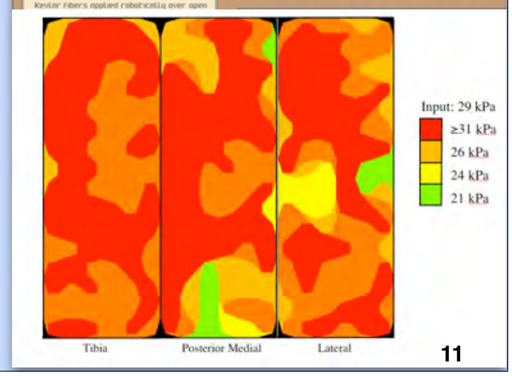
After NIAC – Cerebral Palsy Loading Suit:

- Increase Locomotor Control
- Improved Weight Bearing, stepping, speed & gait
- Improved Range of Motion
- Improved Muscle Tone

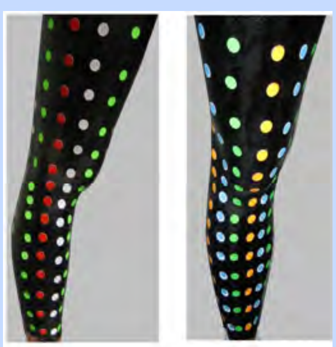
Results: MCP Initial Prototypes

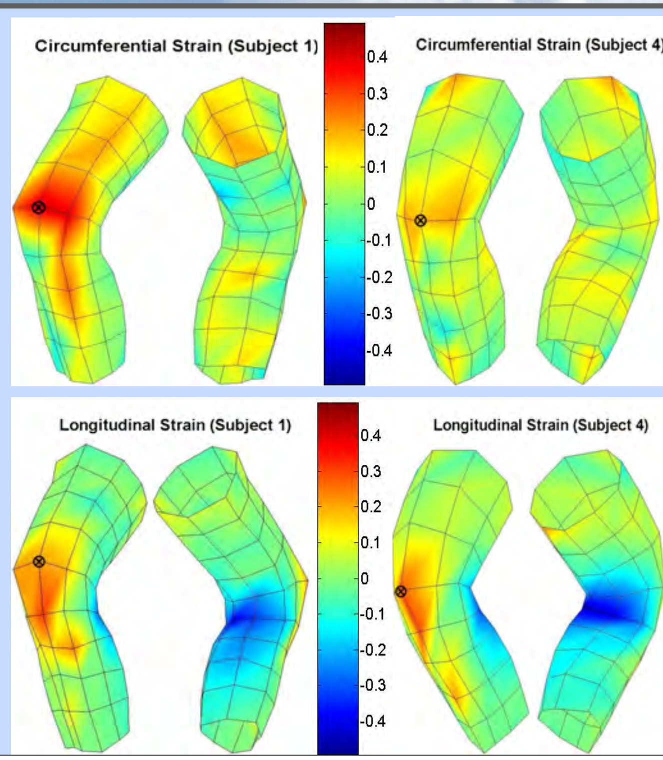
Tibia Medial-Posterior Lateral





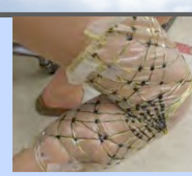
Results: Bio-Suit™ Skin Strain Model



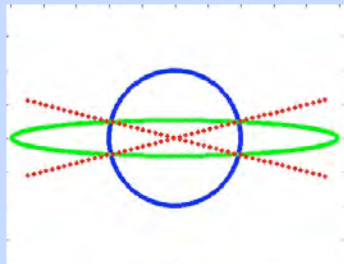


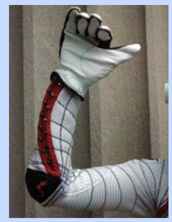
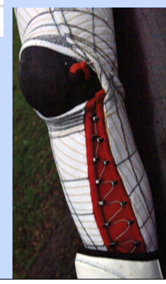
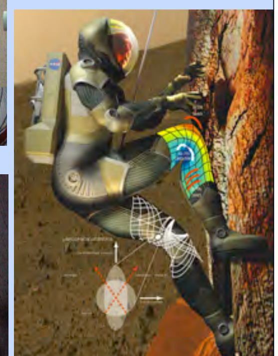
Maximum Mobility & Minimum Energy Design

- Design Patterning: Maximize mobility
  - Mathematical models: nonextension lines
- Minimizing energy
  - Strain energy, stress and modulus
- Active materials (de-couple donning/doffing;
  - Electromechanical polymers (large maximum strain)







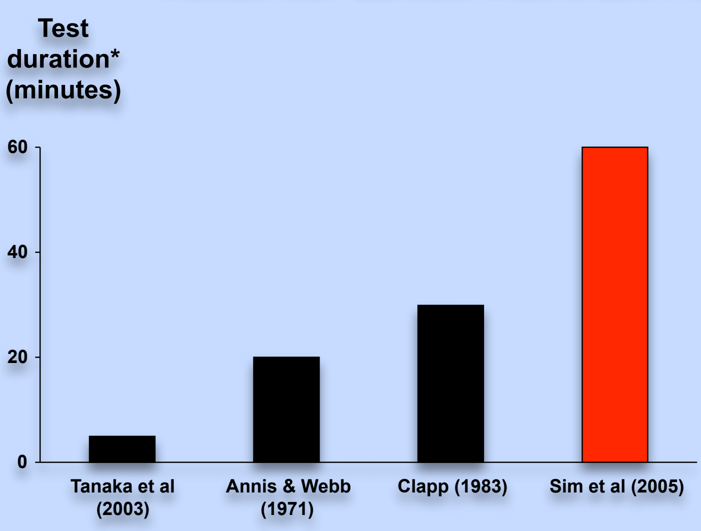




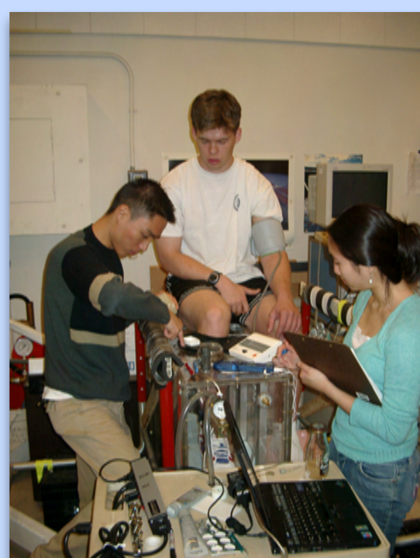
Adapted from A.S. Iberall 1970

Successfully protected a human leg from the effects of external underpressure

ELASTIC BAND PROTOTYPES

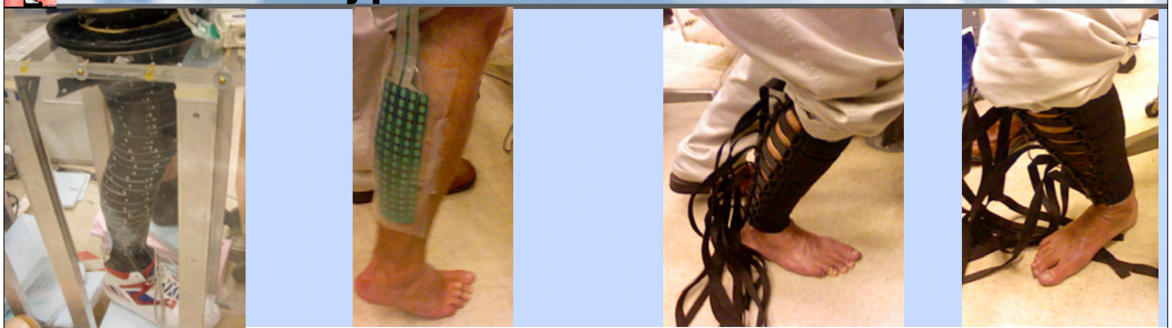
Human MCP Garment Trials in Low-Pressure Chambers



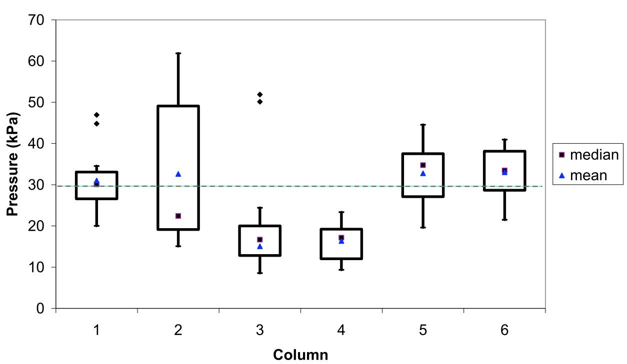


Note: * Excludes pressure ramp-down and ramp-up times

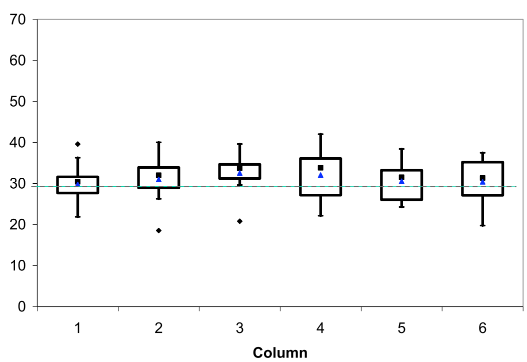
MCP Prototypes: Desired Pressure Achieved!



Front of Leg "Maximum Pressure" Distribution

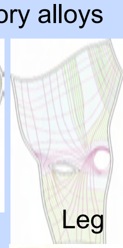


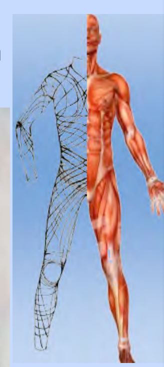
Back of Leg "Maximum Pressure" Distribution



Maximum Mobility: Digital BioSuit™

- From the human form – computer – fabrication
- CAD models – human 3D scans and LoNE
- **340 m** lines of non-extension
  - 140,000 points (stitches)
- Design patterning: **Maximize mobility**
  - Mathematical models: Lines of Non-Extension
    adapted from A. S. Iberall, 1970
- **Minimizing energy**
  - Strain energy and modulus
- **Active materials**
  - Decouple donning/doffing
  - Electromechanical polymers
  - Shape memory alloys



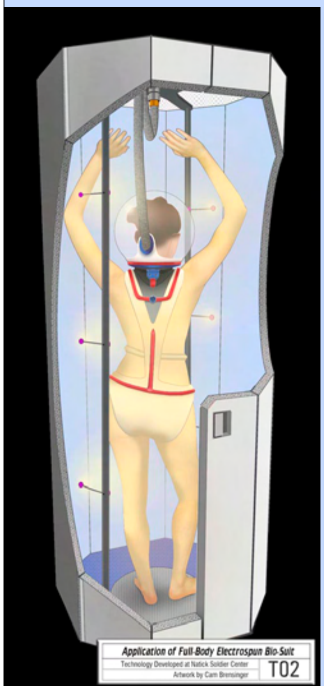


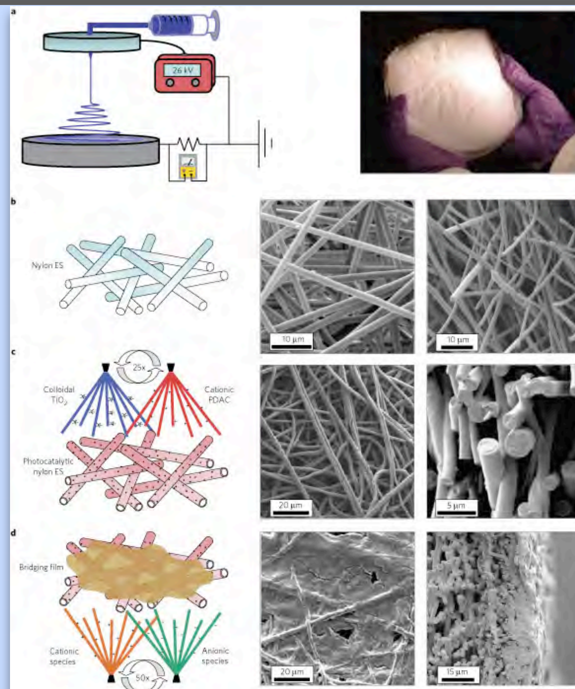
Massachusetts Institute of Technology

TROTTI + ASSOCIATES, INC

DAINESE

Electrospun Designer Materials



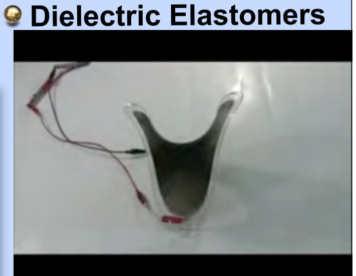


Kevin C. Krogman, Joseph L. Lowery, Nicole S. Zacharia, Gregory C. Rutledge, & Paula T. Hammond, "Spraying asymmetry into functional membranes layer-by-layer, ***Nature Materials***, 8, 512-518, 2009.

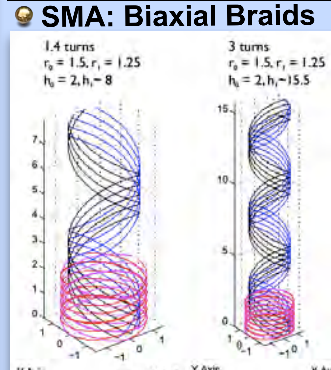
NASA Space Technology Research Fellow – B. Holschuh; Active Materials

Material	Maximum Stress (MPa)	Maximum Strain (%)	Actuation Mechanism	Assessment
Dielectric Elastomer	0.3-7.7	120-380	Applied Voltage (> 1 kV)	Accepted for further study
Piezoelectrics	4.8-110	0.2-1.7	Applied Voltage (1500 V)	Rejected
Shape Memory Alloy	> 200	4-8	Thermal Stimulus	Considered for further study
Stimulus Active Polymer	0.3-180	2-40	Multiple	Accepted for further study
Liquid Crystal Elastomer	0.01-0.45	19-45	Thermal or Electrostatic Stimulus	Rejected
Ferroelectric Polymer	20-45	3.5-7	Applied Voltage (> 1 kV)	Considered for further study
Magnetostrictives	70	0.2	Applied Magnetic Field	Rejected
Ionic Polymer Metal Composite	0.23-15	0.5-3.3	Applied Voltage (1-7 V)	Considered for further study
Carbon Nanotubes	> 20000	0.2-1	Applied Voltage (1-30 V)	Rejected

- Dielectric Elastomers

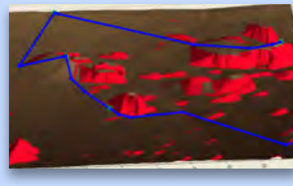


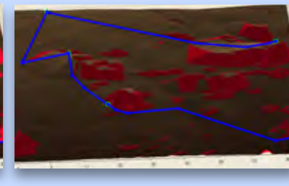
- SMA: Biaxial Braids

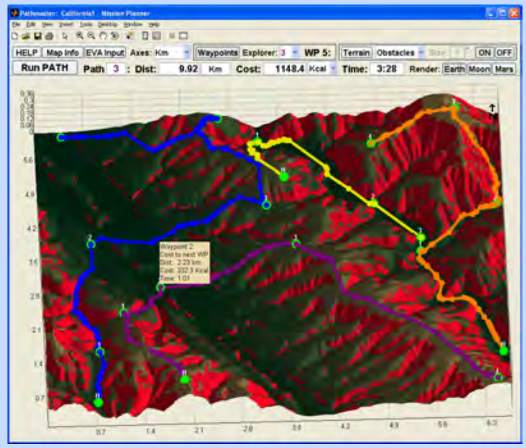


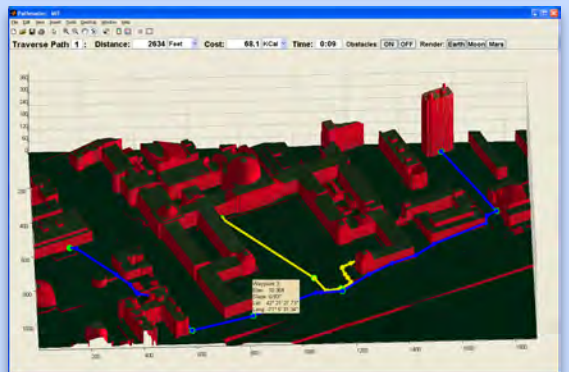
Holschuh, B., Obropta, E., Newman, D, Mechanical Counterpressure Spacesuit Design Using Active Materials, 2011.
Video: ShapeShift - Caad-eap.blogspot.com, 2010

A Day in the Life of a BioSuit™ Explorer



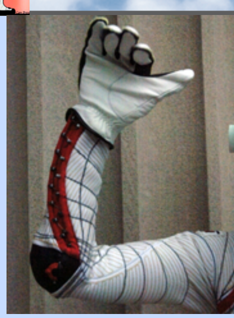


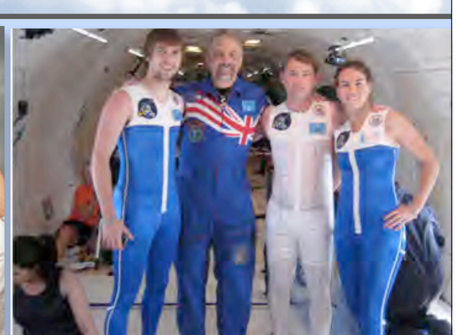




BioSuit™ Time Magazine Best Invention (2007); BBC, NOVA

MET (2008), London (2009, V&A 2011), Paris (2010), AMNH NYC (2011-12)

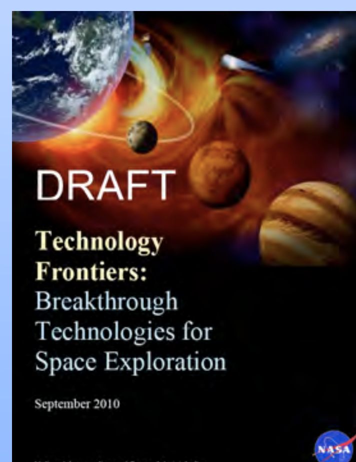


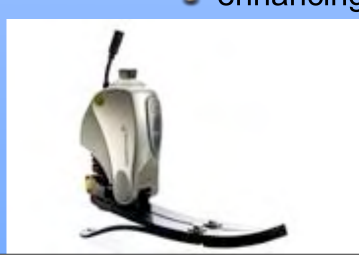


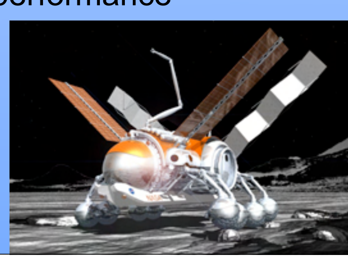
2011 BioSuit™ Helmet & Life Support

Breakthrough Technologies

- Morphing Rovers/Systems
- Roving Hoppers
- Reconfigurable Robots
- Sailboats, Submersibles
- **Super Humans: (MCP)**
  - Augmentation technologies
    - balance, strength and speed
  - Exoskeletons: “Soft Exoskeleton”
  - Active materials
    - enhancing performance







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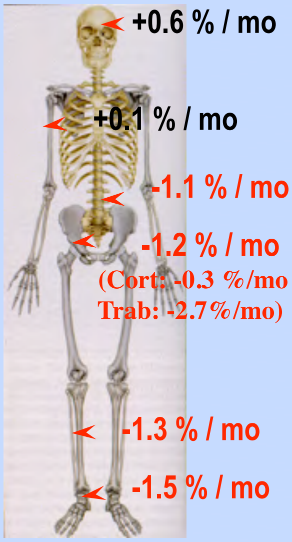
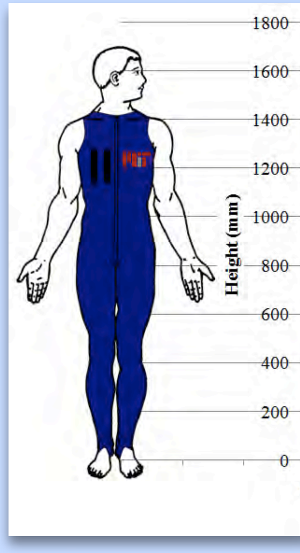
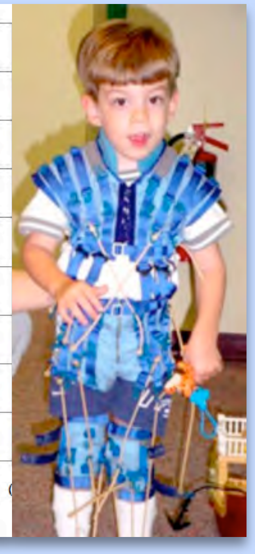
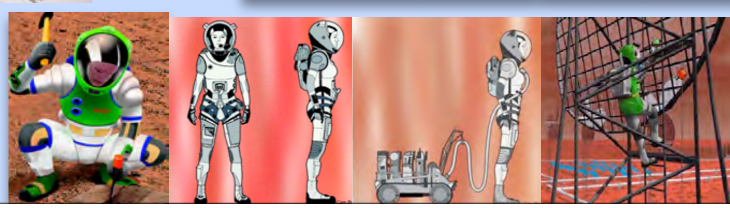
Leveraging *BioSuit™* Design *from Space to Earth (NSF funded)*

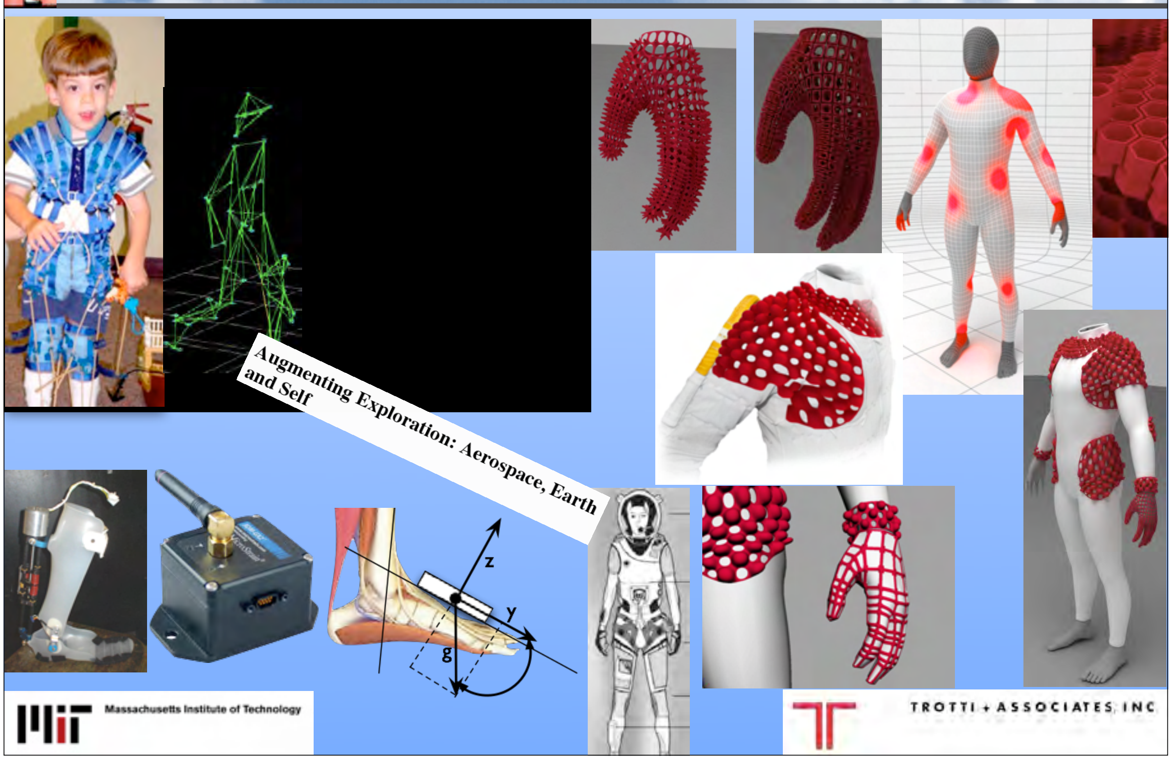








Earth & Space – Comfort & Protection



Thank You!   *Questions?*

Enabling Extreme Exploration through fundamental knowledge of human performance in space, on Mars, and Earth through engineering and design